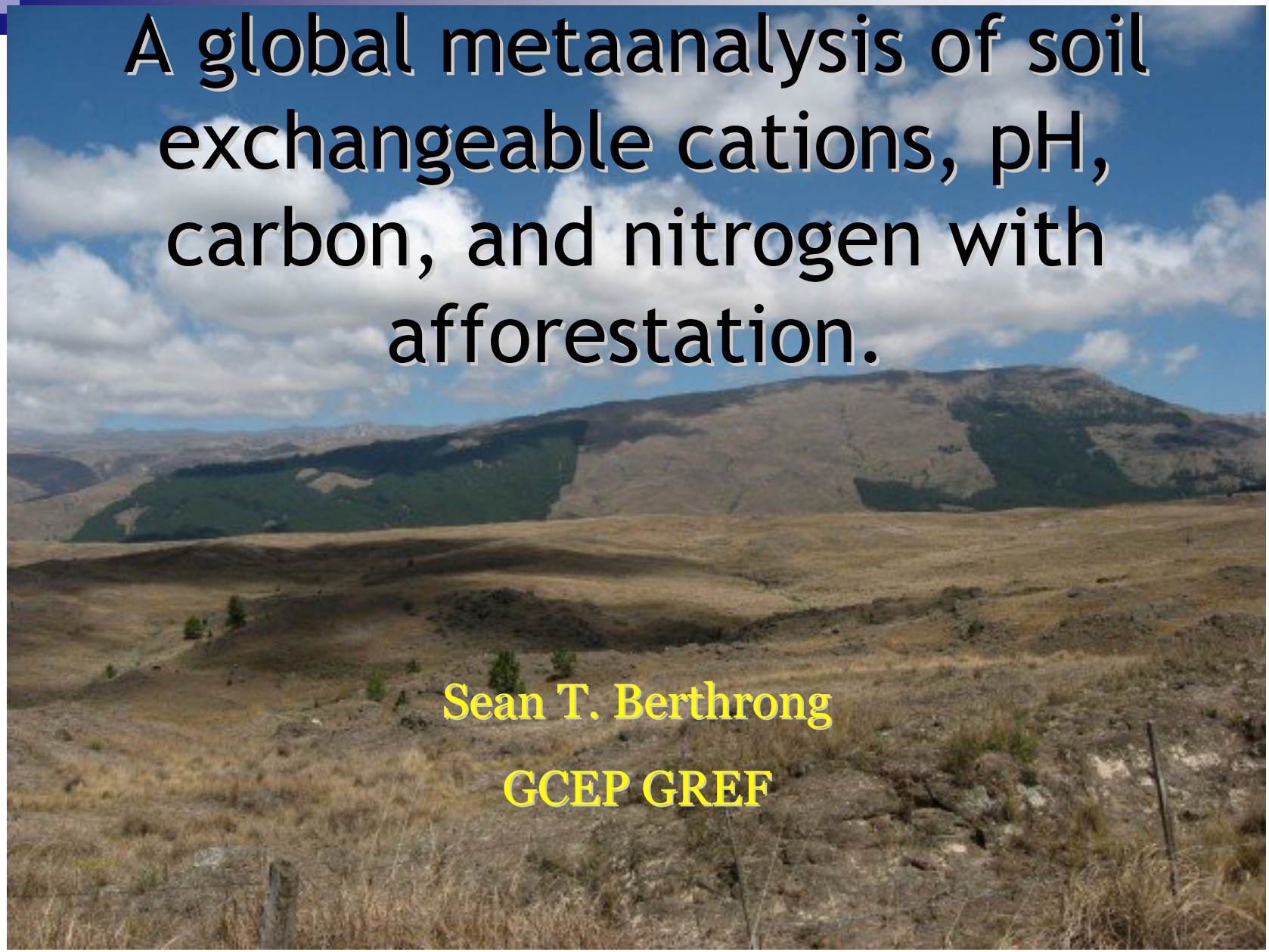
A global metaanalysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation.



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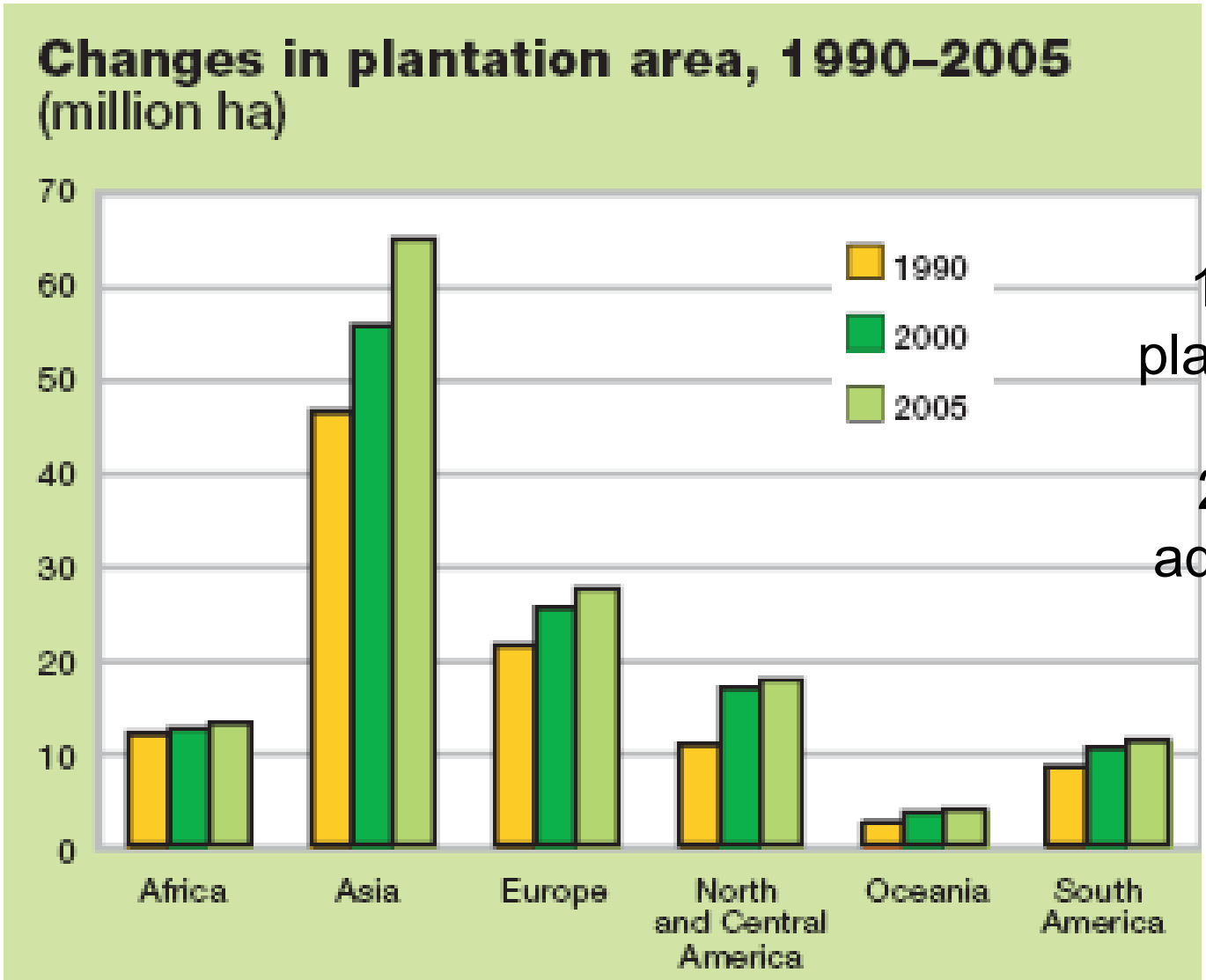
NICHOLAS SCHOOL OF THE ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY

Afforestation

- Kyoto Protocol: Conversion of land that has not been forested for >50 years
- Exotic tree spp
  - *Eucalyptus*
  - *Pinus*
  - *Acacia*

Global Forest Change



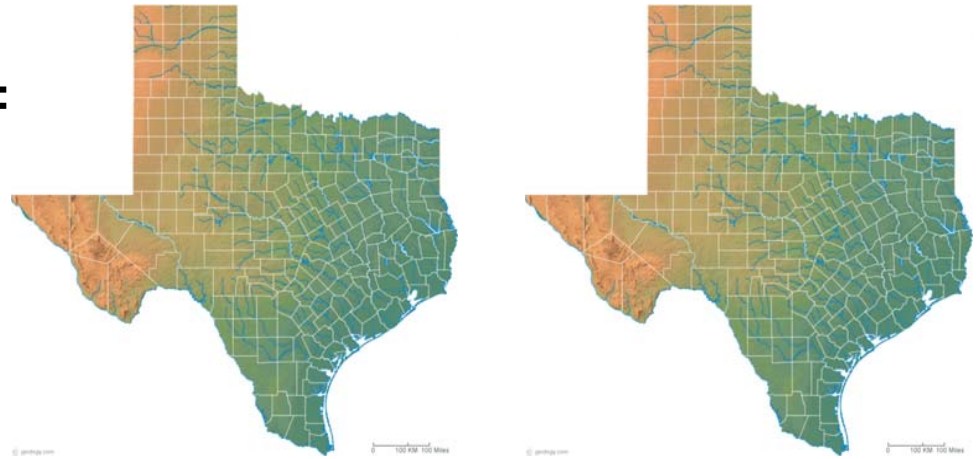
140 million ha plantation globally

2.8 million ha added each year

Source: UN FAO Forest Resource Assessment 2005 and 2001

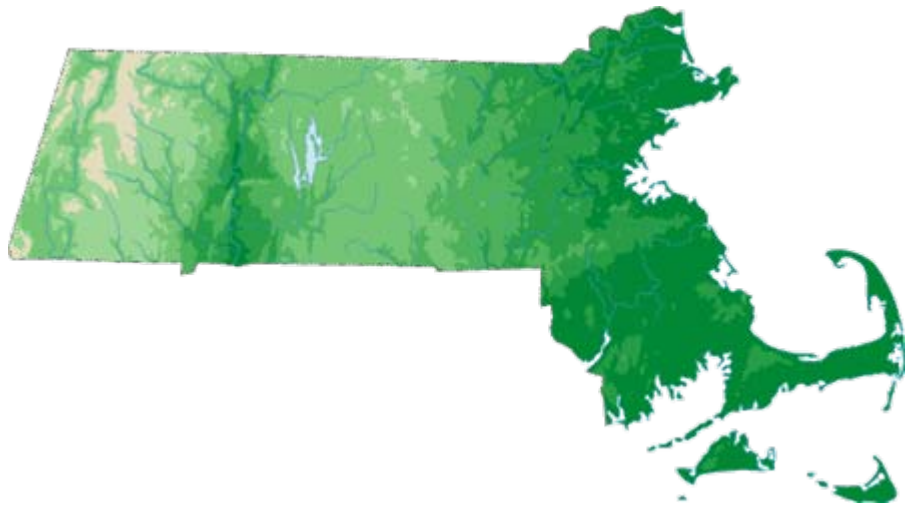
140 million hectares
Afforested total in 2005

=



2.8 million hectares afforested
Per year in the 2000s

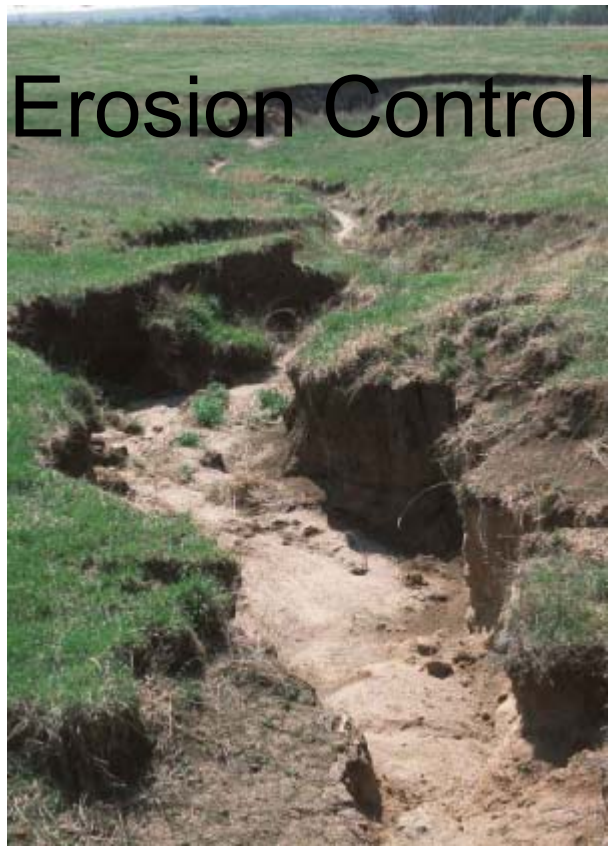
=



Why Afforest?

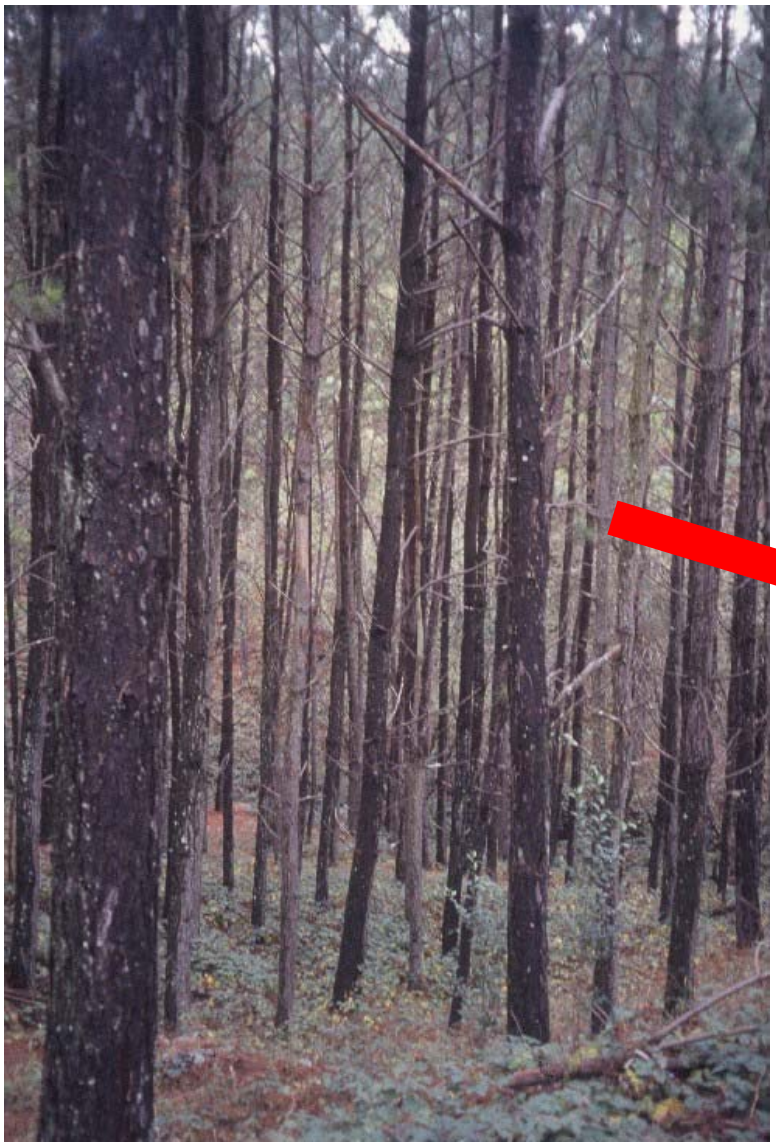
CO_2 Sequestration

Salinization Control



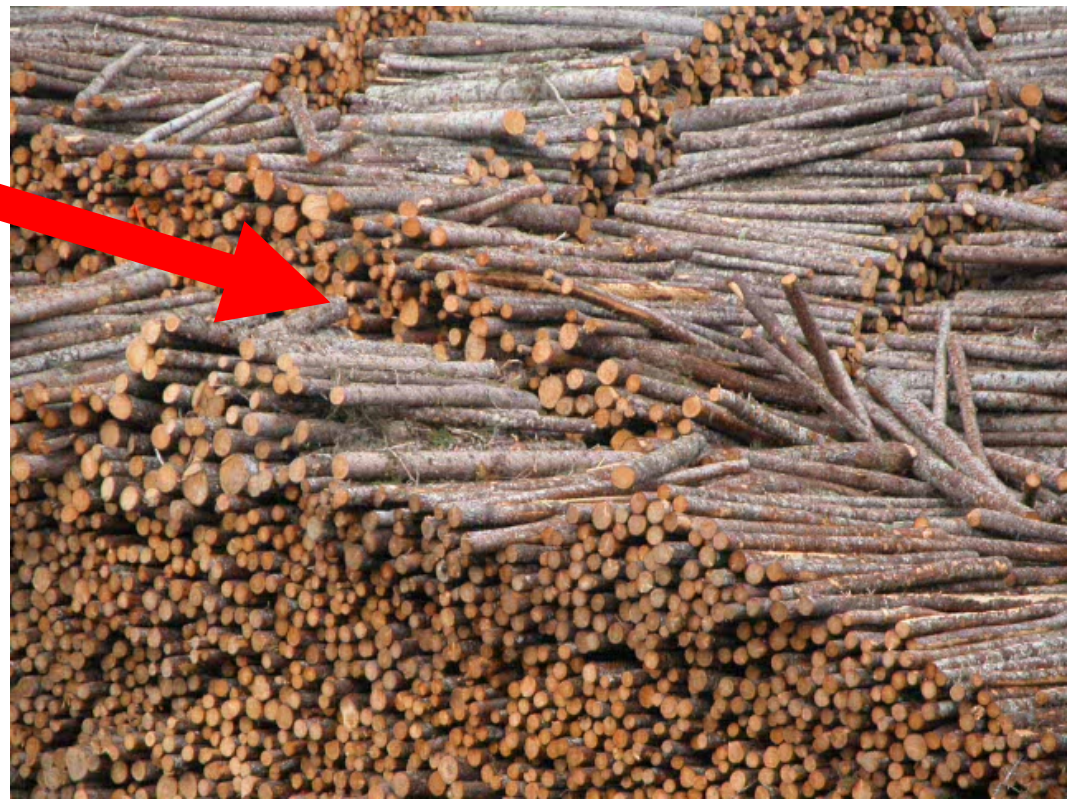
Erosion Control

Why Afforest?



Plantations=3.8% of forest area

However, 35% of Wood products



Source=FAO, 2000

Costs of Afforestation

- Decreased streamflow
- Lower pH
- Salinized stream and groundwater

Depletion of soil nutrients

Project Goals

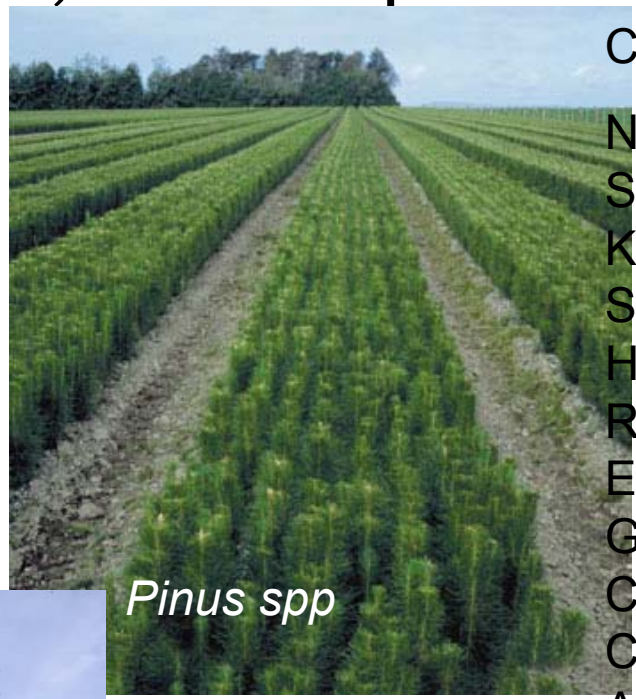
- Create global database of effects of afforestation on grassland soils
- Evaluate effect of afforestation on: Cations, Carbon, Nitrogen, pH
- Long-term sequestration potential
- How to ameliorate effects

Research Approach

- All available published literature on afforestation and soil
  - 71 papers, 153 sites
- Values of grassland and control for exchangeable cations, carbon, nitrogen, pH for mineral soil
- Converted to stocks (g/m^2) with bulk density

$$BD = \frac{100}{\frac{OM\%}{0.244} + \frac{100 - OM\%}{1.64}}$$

The Dataset: 71 studies, 153 independent sites



Countries:

New Zealand, Sweden, United Kingdom, United States (including Hawaii and Puerto Rico), India, Ecuador, Argentina, Germany, Brazil, China, Russia, Costa Rica, South Africa, Belgium, Denmark, Australia, Philipines, Chile, Italy, Spain

Research Approach, Continued

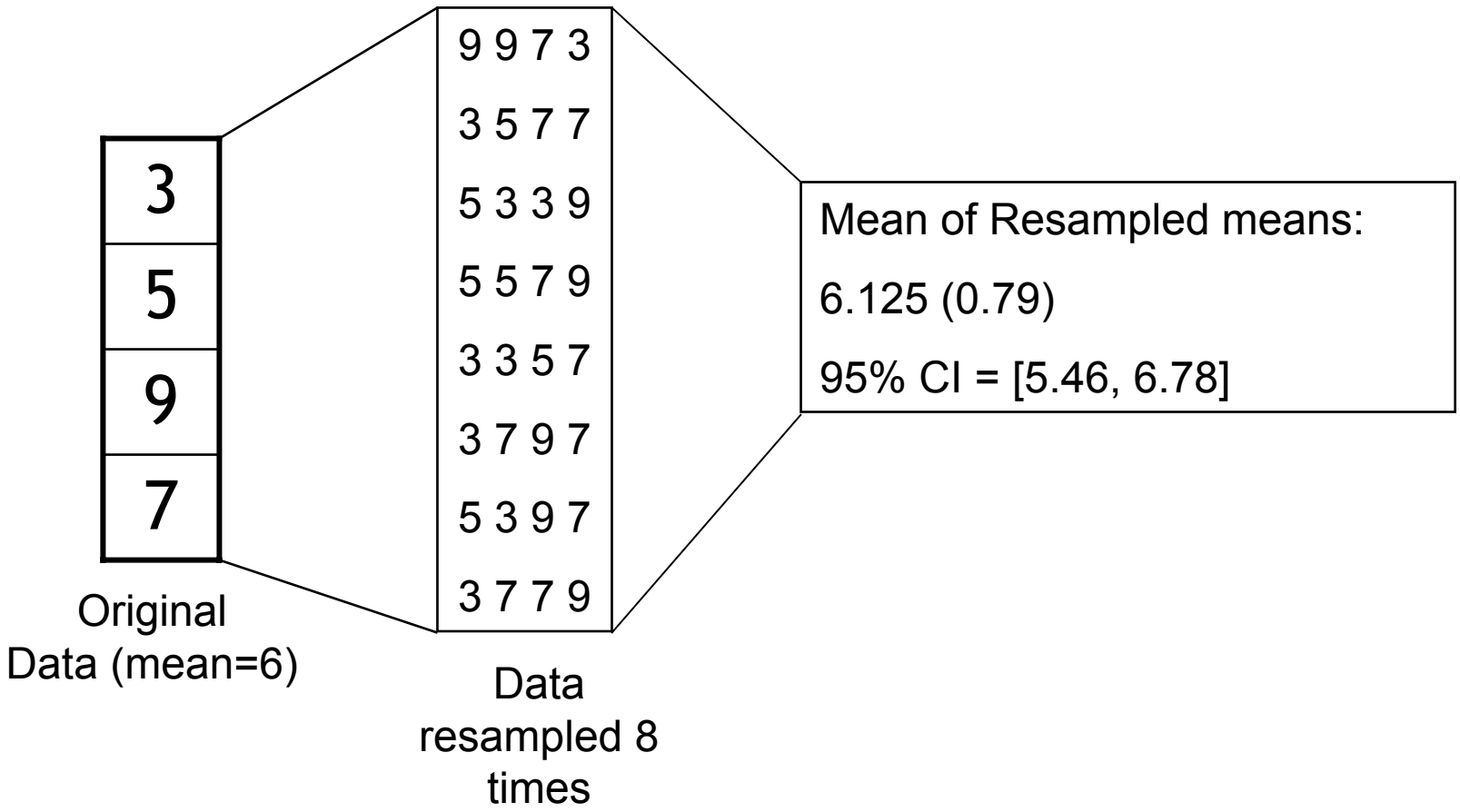
- Effect calculated as response ratio

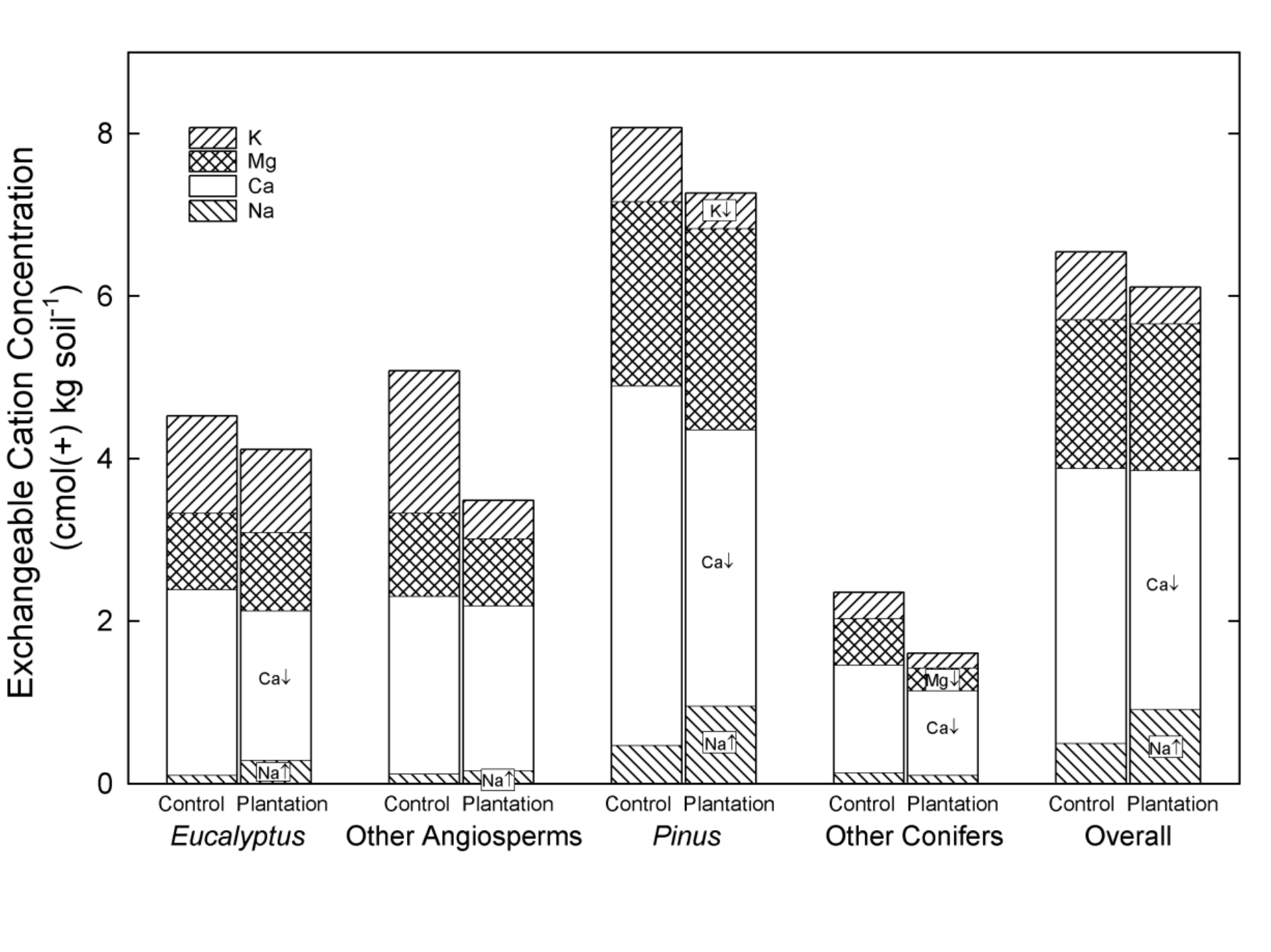
$$lr = \ln\left(\frac{X_T}{X_C}\right)$$

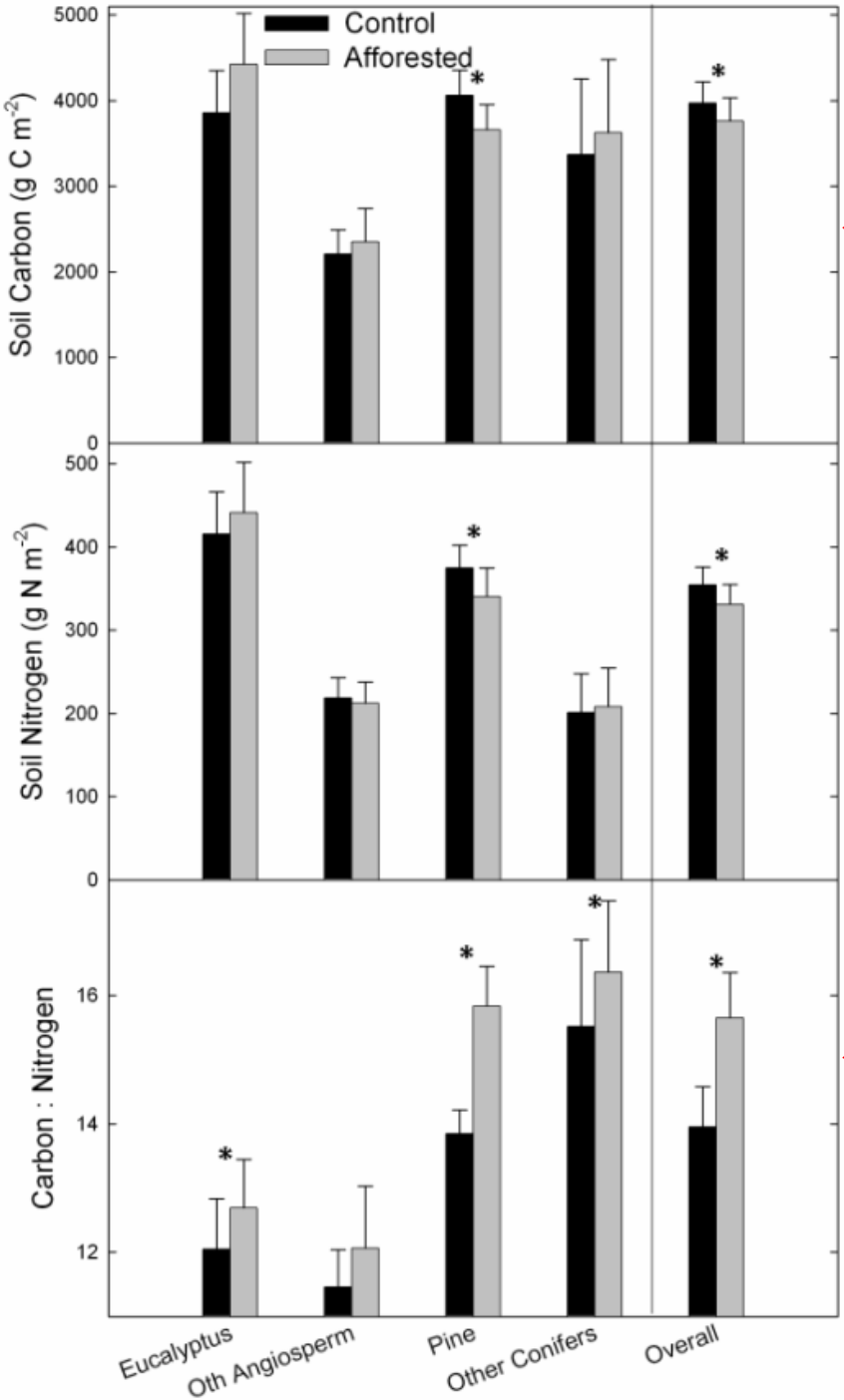
- Where X_T= value for plantation and X_c= value for control
- Standardizes for differences in control (grassland) values
- Values centered at 0; increase in afforestation value=positive lr; decrease=negative lr

Bootstrap: Non-parametric technique

- Resampling with replacement to generate 95% confidence intervals of response ratio




Exchangeable Cation Concentration
(cmol(+) kg soil^{-1})
0
2
4
6
8
K
Mg
Ca
Na
Ca↓
Na↑
K↓
Ca↓
Na↑
Na↑
Mg↓
Ca↓
Ca↓
Na↑
Control
Plantation
Eucalyptus
Other Angiosperms
Pinus
Other Conifers
Overall



Decrease due to pine afforestation

Decrease due to afforestation with pine, eucalyptus, and conifers

Carbon Loss and Sequestration?

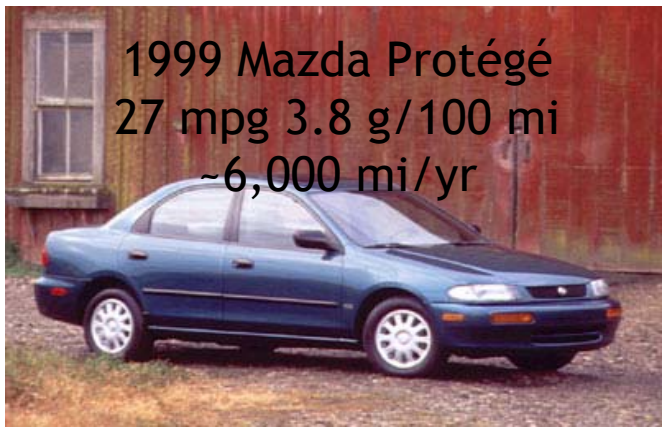
- Average soil C loss = 4.1 Mg C / ha
- Average 20 year rotation plantation = ~75 Mg C / ha
- So ~5.5% of biomass C sequestered is lost from soil C

Digression: C loss in Context

Pine plantation sequesters
~3750 kg CO_2-C per hectare year

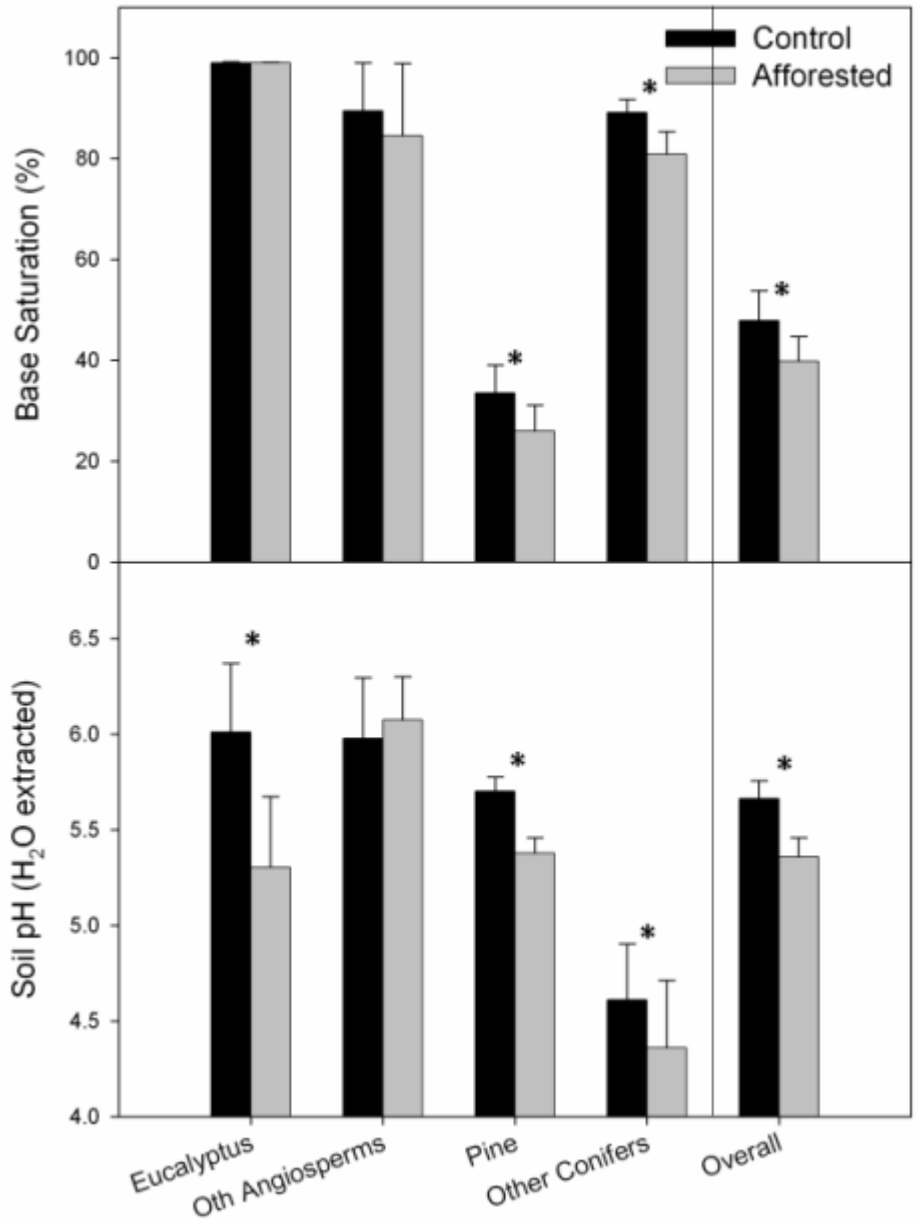
Soil C losses =
~205 kg CO2-C per hectare year

+



= 573 kg CO_2 per year for me
1146 normal US driver

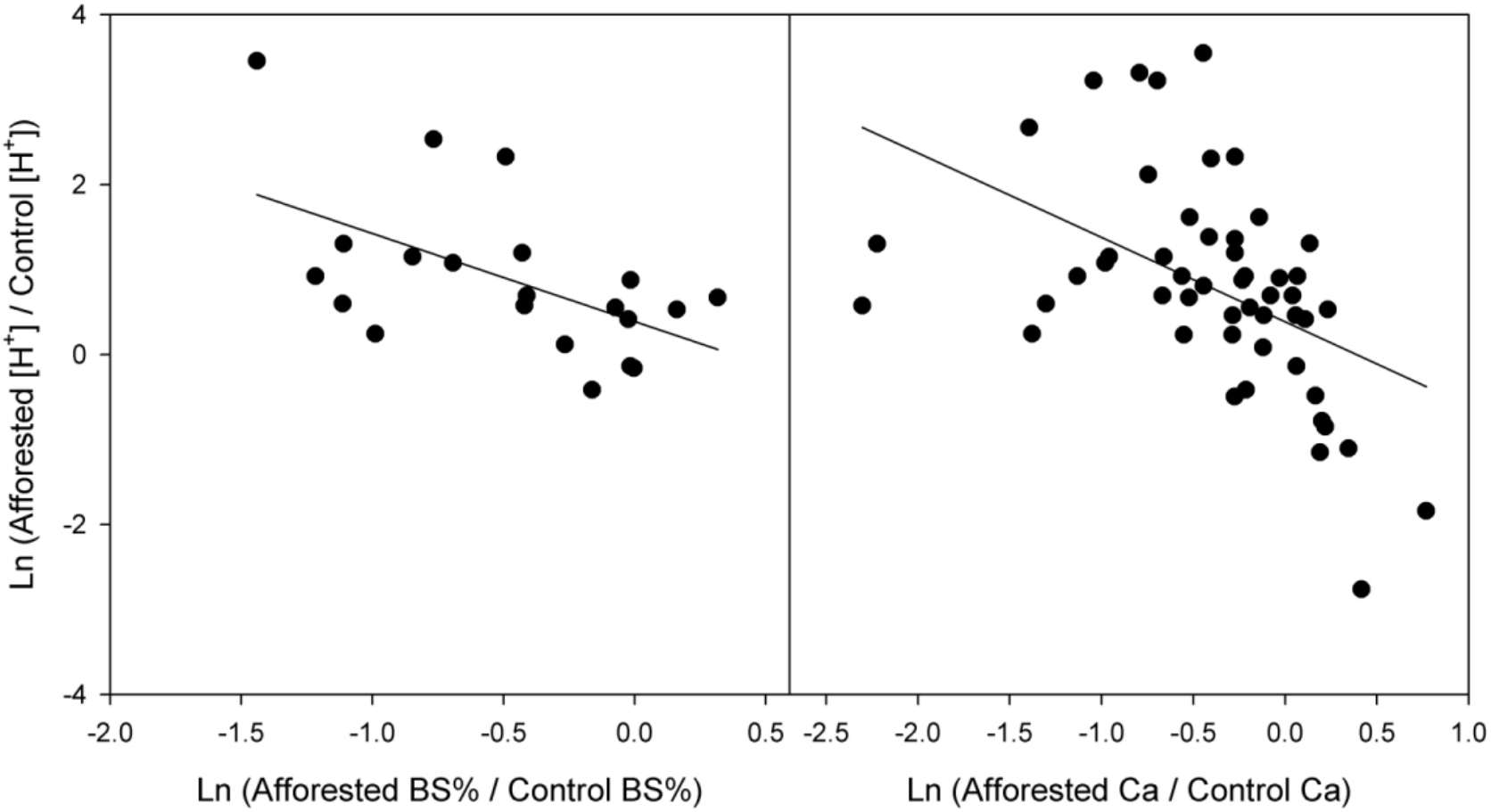
$\therefore$ 1 ha pine = around 6.2 of my cars
Or 3.1 average US cars



Acidification due to Eucalypt, Conifers, and Pines

Base Saturation loss due to Pines and Conifers

Source of Acidification

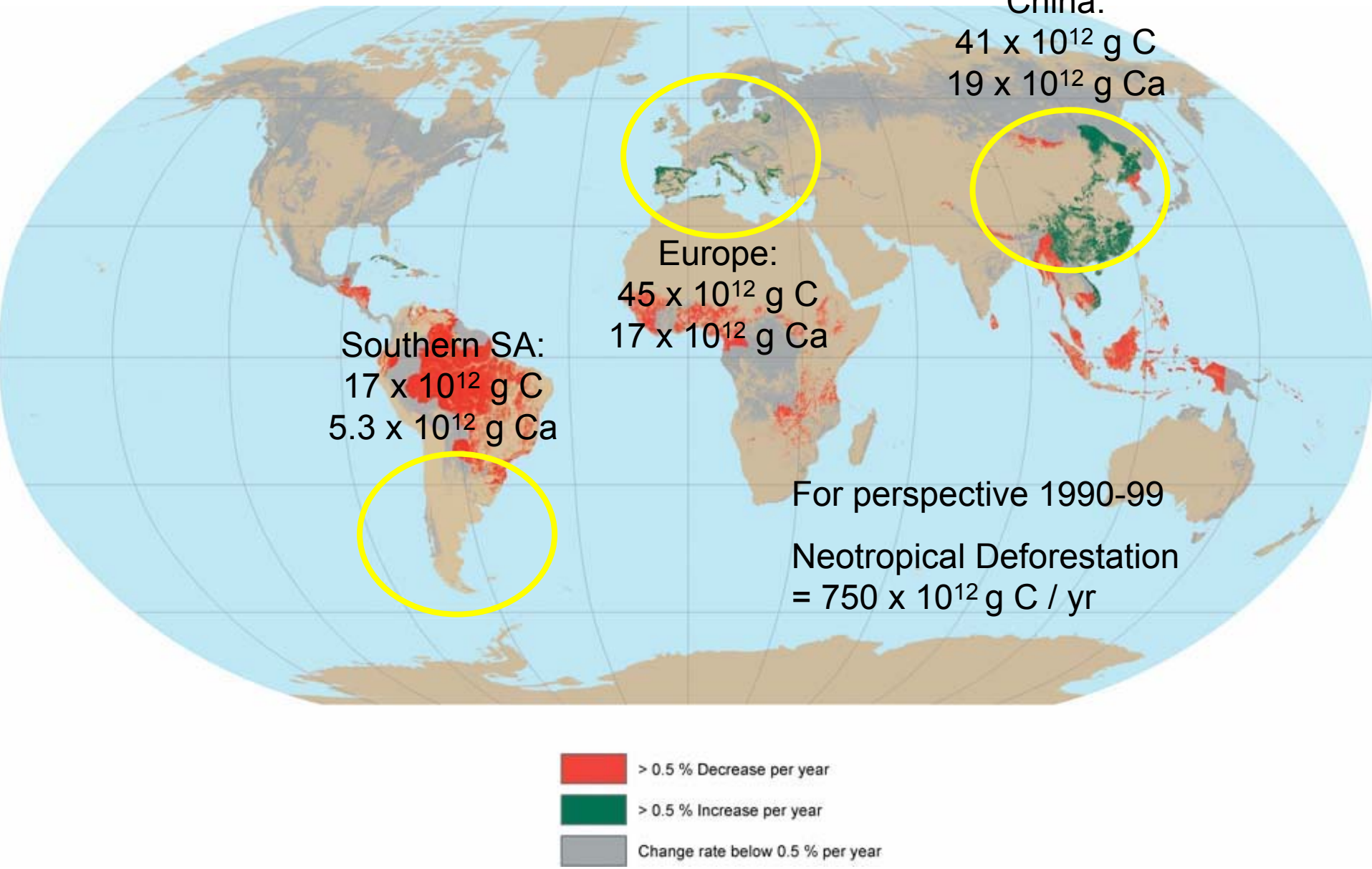


Spearman's ρ=-0.58
p=0.006, N=21

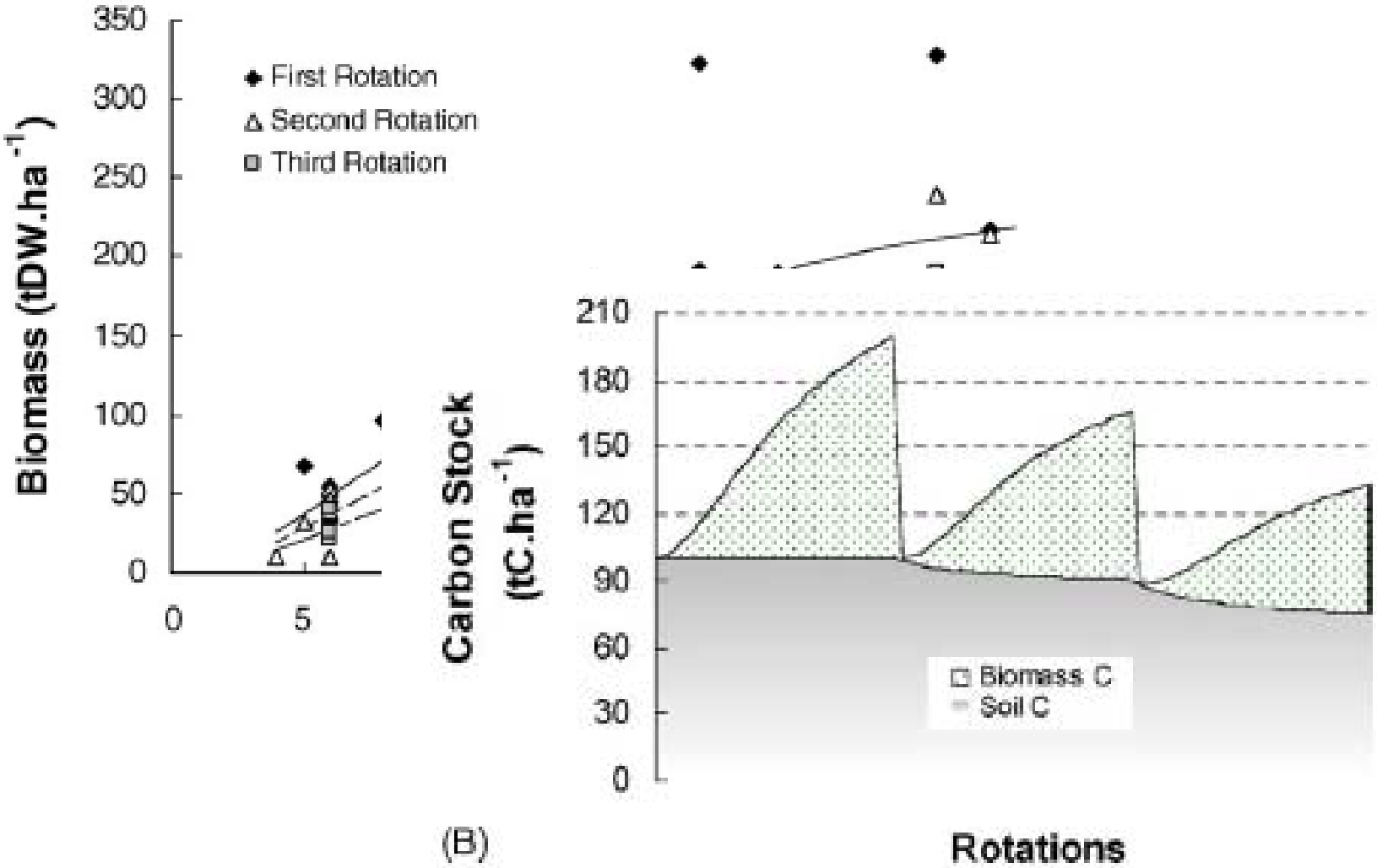
Spearman's ρ=-0.56
P<0.0001, N=51

Result Summary

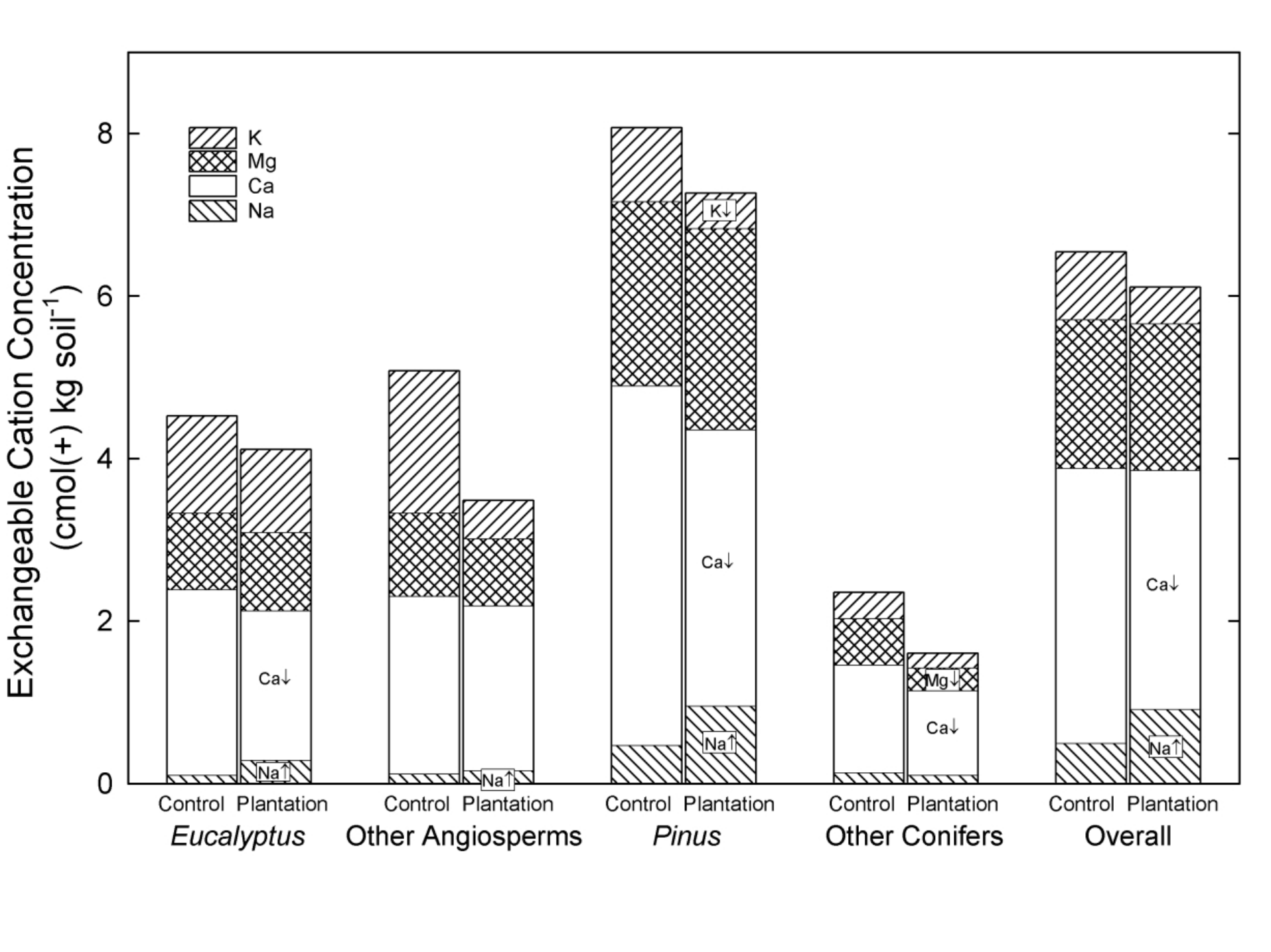
- Loss of exchangeable cations with afforestation
- C and N loss, but only with pines
  - But C:N increases
- Acidification common, related to cation losses


China:
41 x 10^12 g C
19 x 10^12 g Ca
Europe:
45 x 10^12 g C
17 x 10^12 g Ca
Southern SA:
17 x 10^12 g C
5.3 x 10^12 g Ca
For perspective 1990-99
Neotropical Deforestation
= 750 x 10^12 g C / yr
> 0.5 % Decrease per year
> 0.5 % Increase per year
Change rate below 0.5 % per year

Productivity through time



Zhang et al. 2004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0
2
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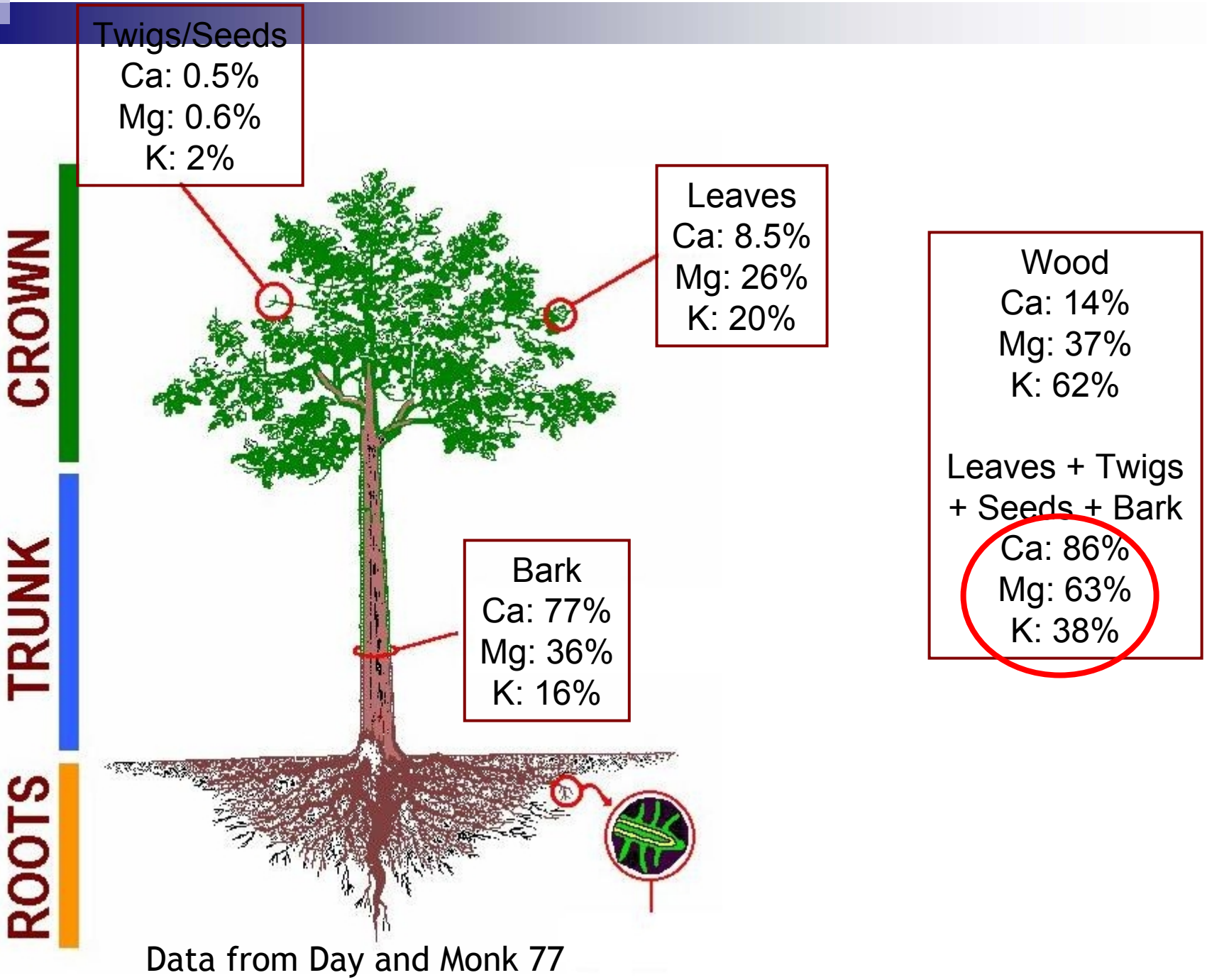
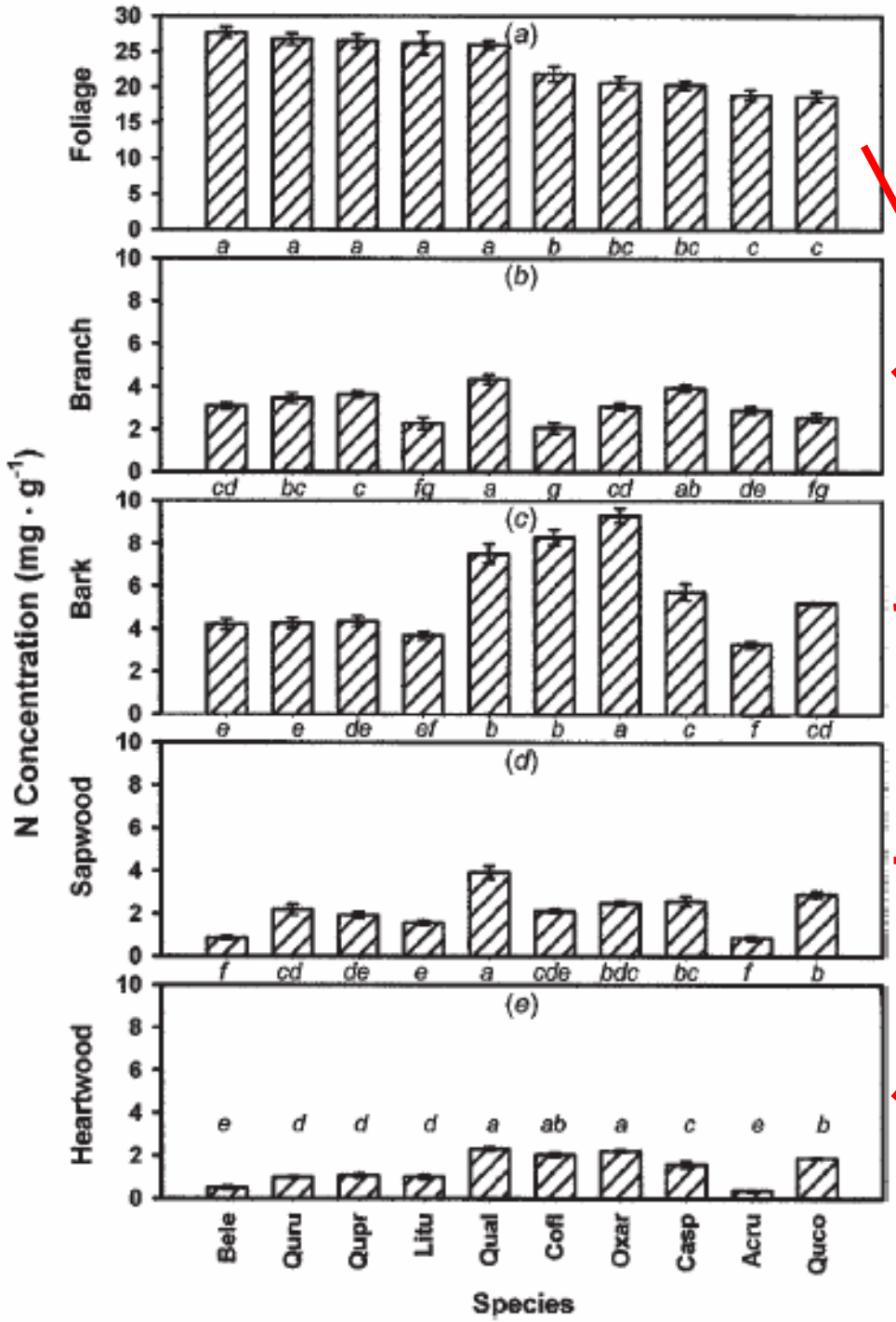
Overall


Twigs/Seeds
Ca: 0.5%
Mg: 0.6%
K: 2%
Leaves
Ca: 8.5%
Mg: 26%
K: 20%
Wood
Ca: 14%
Mg: 37%
K: 62%
Leaves + Twigs + Seeds + Bark
Ca: 86%
Mg: 63%
K: 38%
Bark
Ca: 77%
Mg: 36%
K: 16%
CROWN
TRUNK
ROOTS
Data from Day and Monk 77



N in Foliage + Branch + Bark = 88%

N in Woody Biomass = 12%

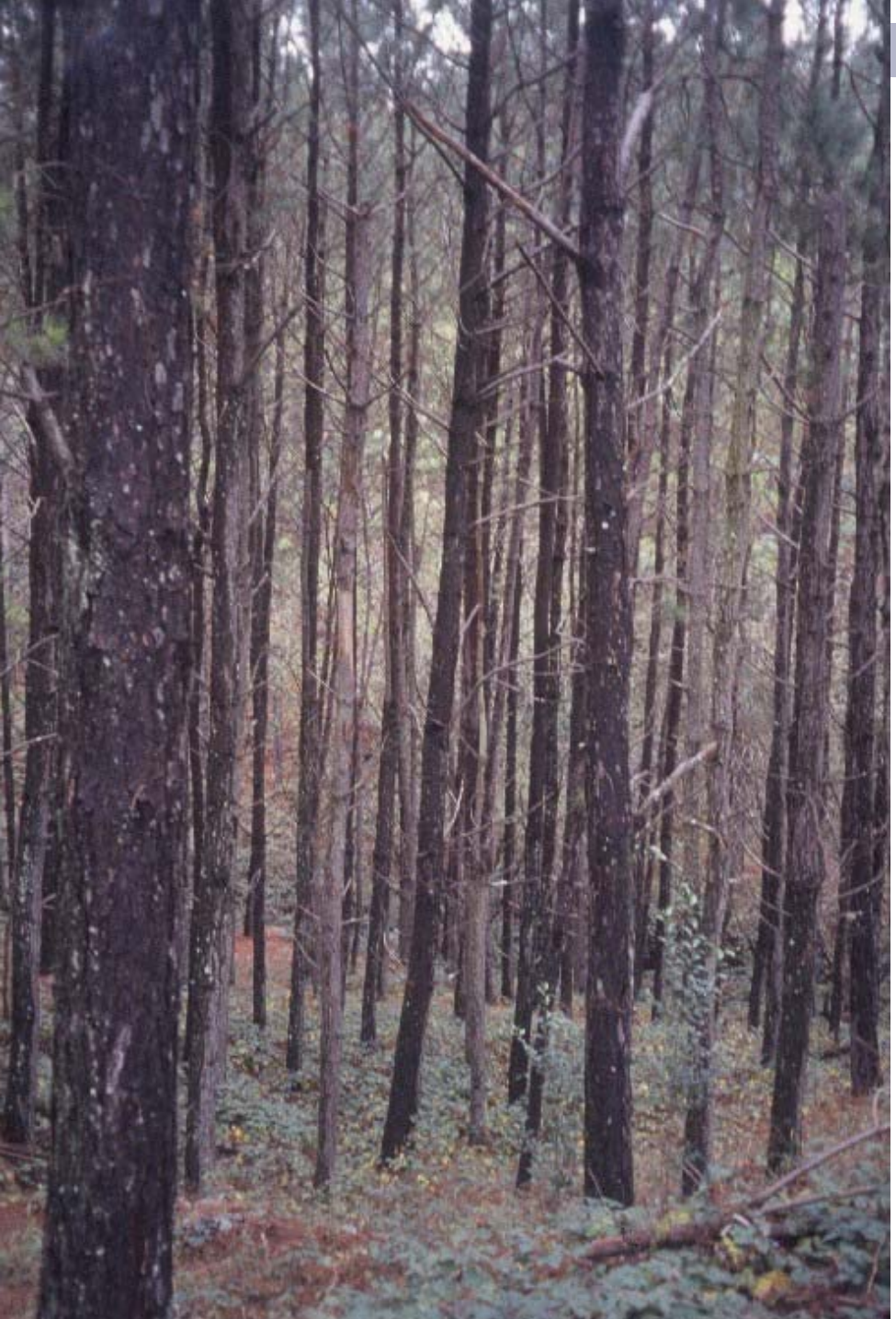
From Martin et al. 1998

Potential Amelioration

- On-site debarking and slash retention conserves cations and N
- Burning=net losses of C and N (combustion), non-burned=increased production (Mendham 2003)
- Logging residue retention also decreases compaction and erosion

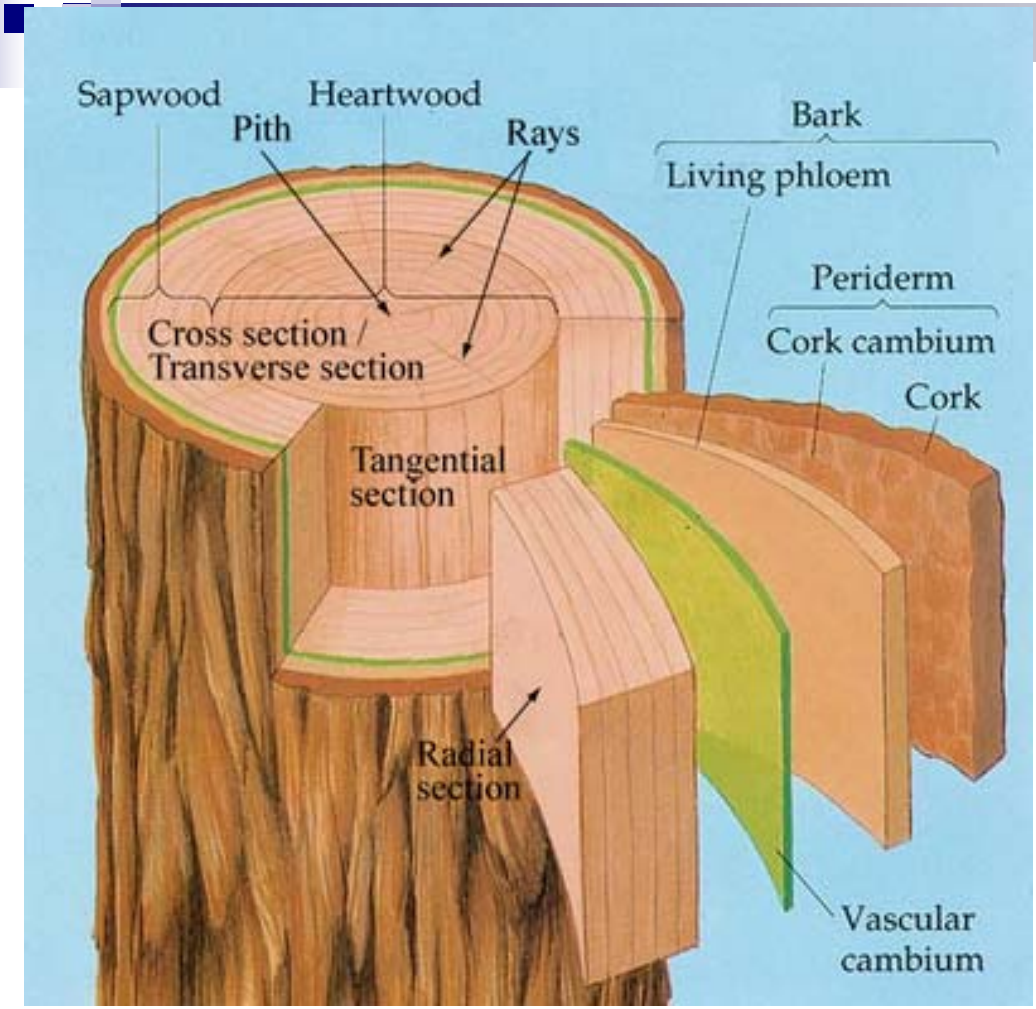
Conclusions

- Afforestation decreases the soil cation complex, carbon, N, pH, and BS%
- Represents significant portion of regional carbon pools that should be integrated into models
- Potential for sustainability through slash retention

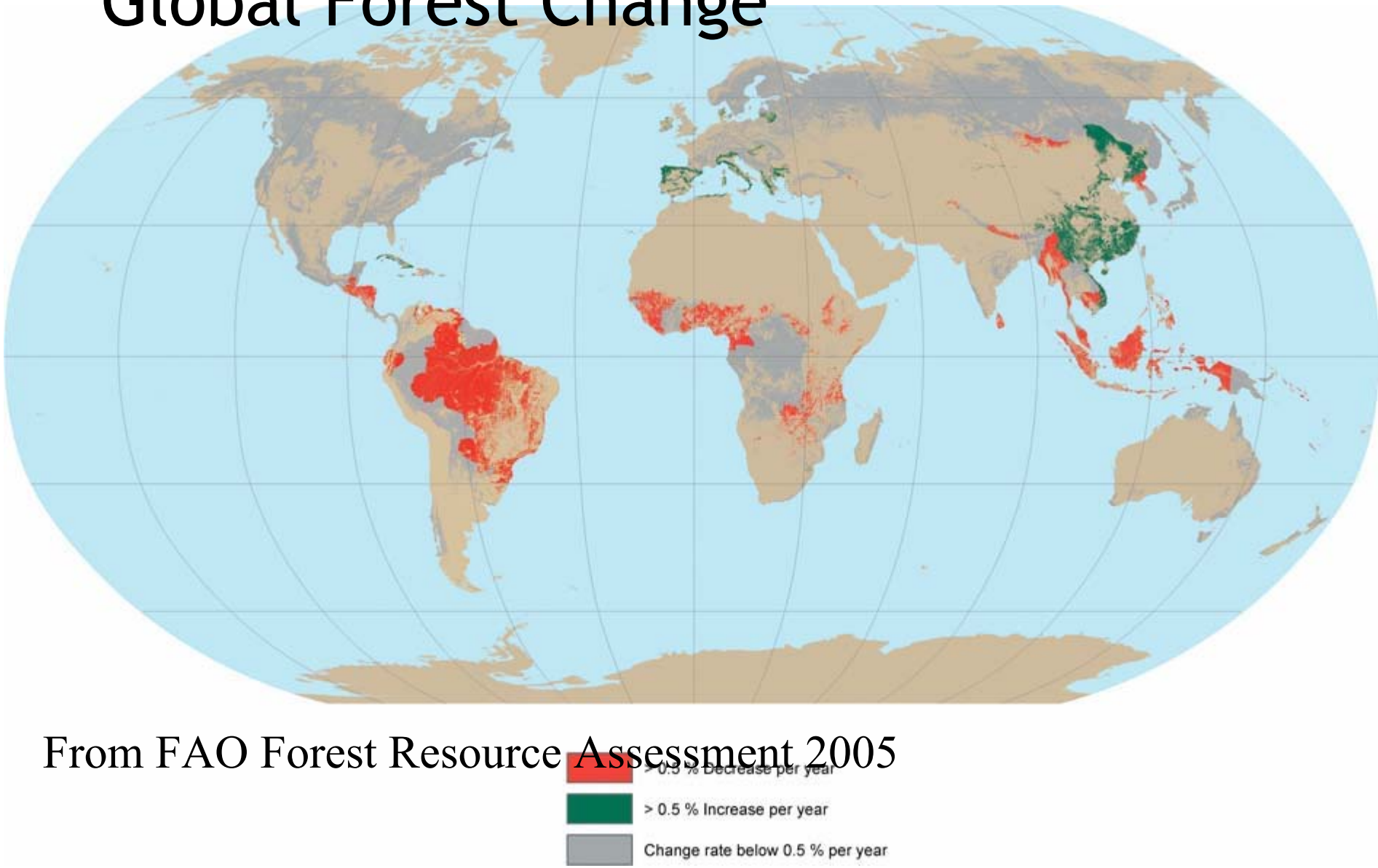


Acknowledgments

- Rob Jackson, Esteban Jobbagy (co-authors)
- Will Cook, Justin Baker database and stats help
- Funding: NSF, Duke CGC
- GCEP: Jeff, Nancy, Milton, Rick


Sapwood
Heartwood
Pith
Rays
Bark
Living phloem
Periderm
Cork cambium
Cork
Cross section
Transverse section
Tangential section
Radial section
Vascular cambium

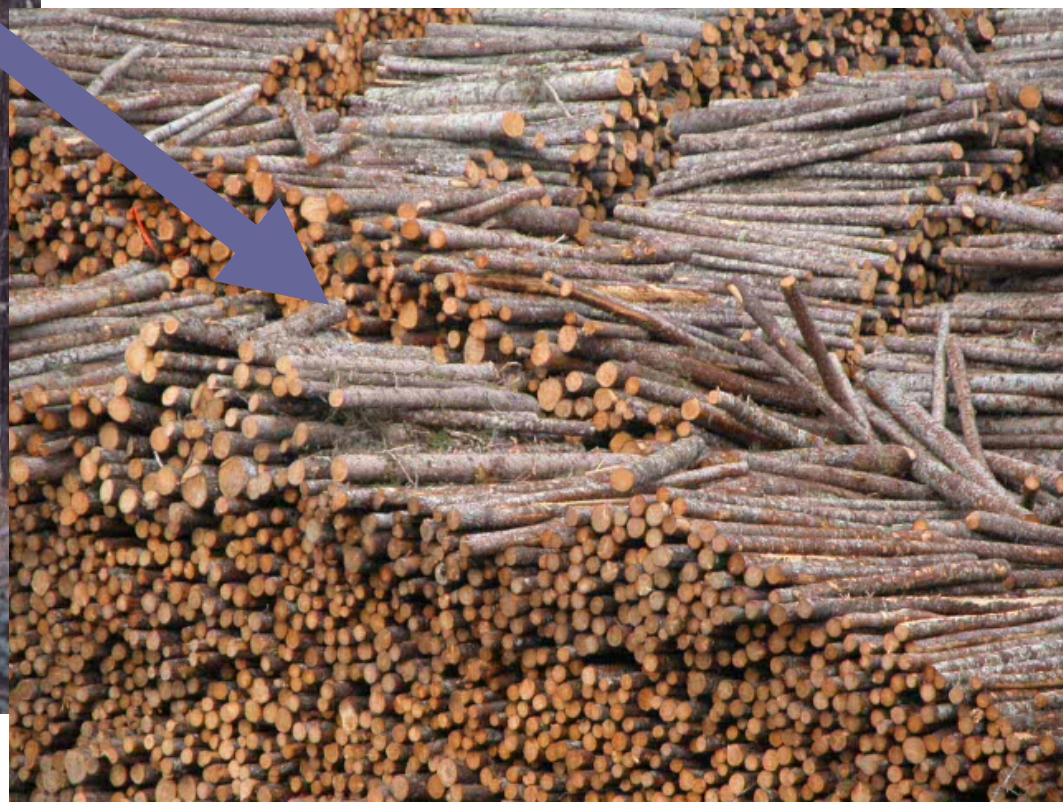
Global Forest Change



From FAO Forest Resource Assessment 2005

Plantations=3.8% of forest area

However, 35% of Wood products



Source=FAO, 2000

Afforestation in South America

- Afforestation: Human conversion of land that has lacked trees for at least 50 years (Kyoto protocol) to forest.
- Historically Treeless
- Plantations as old as 150 yrs; many plantations starting 10-15 yrs